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LA-UR--87-150

DE87 005105

TITLE MICROWAVE-INDUCED AIR BREAKDOWN IN A FREE AIR GEOMETRY

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MACTED 1988

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Introduction

Microwave-induced air breakdown requires high electric fields for short pulse irradiation at low pressures (pressures below the minimum condition of equal microwave frequency and electron momentum exchange rate). An effect which may occur in this parameter regime is the rapid rise of the electron energy above the value for the peak ionization rate [1]. This unusual condition can alter the qualitative breakdown behavior. Only limited data exists under these conditions [2,3]. Moreover, experiments with material walls removed from the breakdown region are needed to allow for the increased electron mean free path. We report on trial experiments, using an open geometry, to measure the breakdown behavior of short, intense microwave pulses in low pressure air.

Experimental Results

The experiments were conducted at the Santa National Laboratory RF Effects Facility. A high voltage magnetron produced 10 ns long pulses at 2.9 GHz with 0.5 GW output. The pulse was relayed into two series of axis parallel reflectors. These reflectors imaged the microwaves into a ~ 15 cm area inside a 10 cm diameter cylindrical pressure cell with 2 cm pyrex walls. Seed ionization was provided by x-ray emission from the magnetron.

Several results of primary interest are luminosity flux, corrected for the transit time from the microwave focus, are compared in Figures 1 and 4 for 0.4 and 20 Torr pressure conditions, respectively. 20 Torr is just above the minimum breakdown threshold while 0.4 Torr is well below [4]. Observations at the lower pressure include weak attenuation of the microwaves and a slow luminosity decay. An unexpected delayed second luminosity peak is also observed which may be associated with high electron temperatures, as discussed below. Both temperatures are also supported by the presence of the dominance of the $H\gamma^1$ 914 Å band in the spectra.

In Figures 2 and 5, CCD camera images of

the air breakdown are compared in shots similar to those above. The entrance wall of the cell is aligned with the left side of the contour image while the microwave path is indicated by a horizontal bar. An obscuring structural member of the cell is apparent as a vertical cut in the contours near the entrance. The image indicates a more diffuse pattern transverse to the beam at the lower pressure, as expected for the larger electron mean free paths. Also, the intensity modulation resulting from the interference of the weak microwave reflection from the exit wall is observed to be smaller at the lower pressure.

Theoretical Modeling

To confirm that low pressure breakdown behavior is consistent with high temperatures, the experiment was simulated with a 1-D Fluid Model [1]. The pulse is propagated as a plane wave through the pressure cell geometry, including reflections from the pyrex walls. Spatial diffusion and ponderomotive effects are neglected. Figures 3a and 3b show density distribution along the beam axis for the two pressures. It is first observed that the modulation in density along the beam is smaller at lower pressure, in qualitative agreement with the luminosity imaging. Figure 3c shows that the expected temperature at low pressure is thousands of eV, well above the ~ 100 eV peak in ionization rate. It is noted that the ionization rate may then be expected across the interference pattern. Simulations at both pressures indicate the strongest breakdown occurs at the entrance wall, reaching above the critical density of 10^{11} cm⁻³. This result is also in agreement with the CCD image data. Furthermore, a slow rise (~ 10 ns) to critical density is predicted for 0.4 Torr in support of the experimental observation of strong microwave transmission.

A unique feature of the low pressure data is the existence of a second peak in the $H\gamma^1$ emission after the termination of the microwave pulse. An explanation of this phenomena evolves from the prediction of very high temperatures.

The first peak results from the initial electron avalanche and subsequent slow density decay due to electron attachment. However, the peak in the excitation cross section occurs at ~ 15 eV [4]. Hence, as the electrons cool after the microwave pulse from thousands of eV to tens of eV, a larger excitation rate ensues with a greater number of N_2 molecules being excited. Testing of this hypothesis is being pursued in further experiments and temporal modeling of spectra.

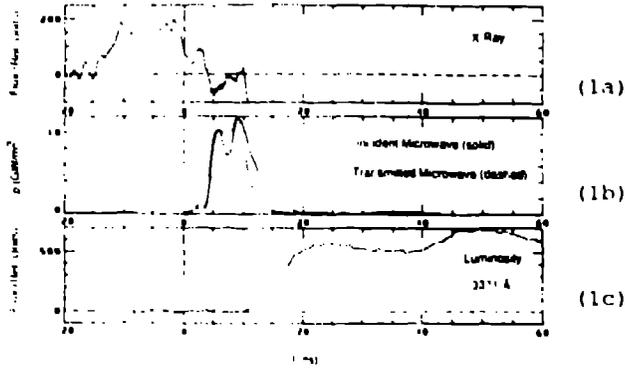


Fig. 1. Shot #2, 0.4 Torr. Temporal behavior.



Fig. 2. Shot #3, 0.4 Torr. Luminosity contours.

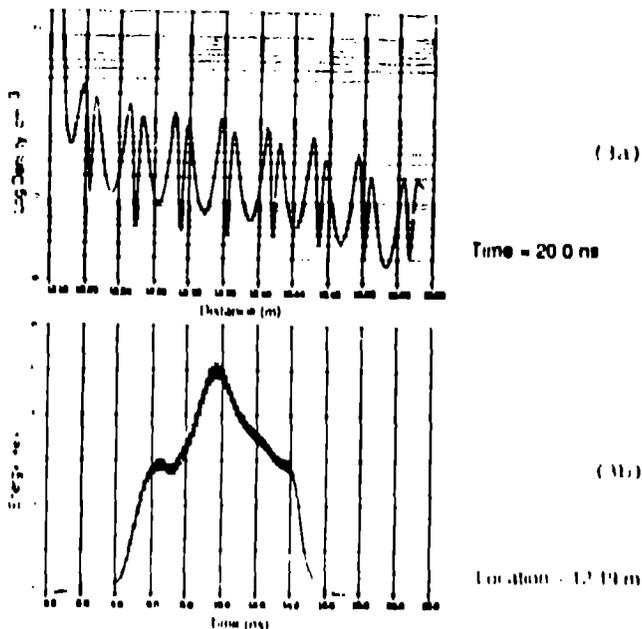


Fig. 3. Shot #2, 0.4 Torr. Model predictions.

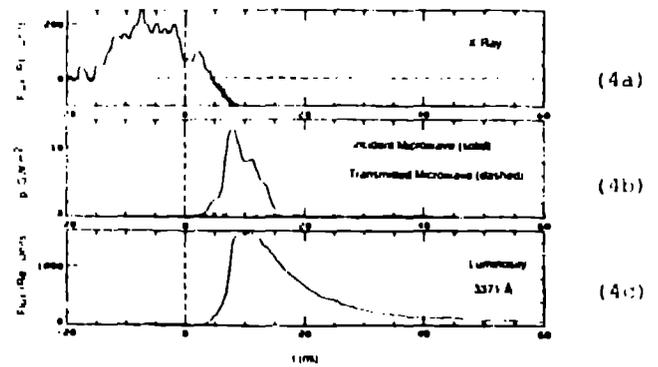


Fig. 4. Shot 64, 20 Torr. Temporal behavior.



Fig. 5. Shot 64, 20 Torr. Luminosity contours.

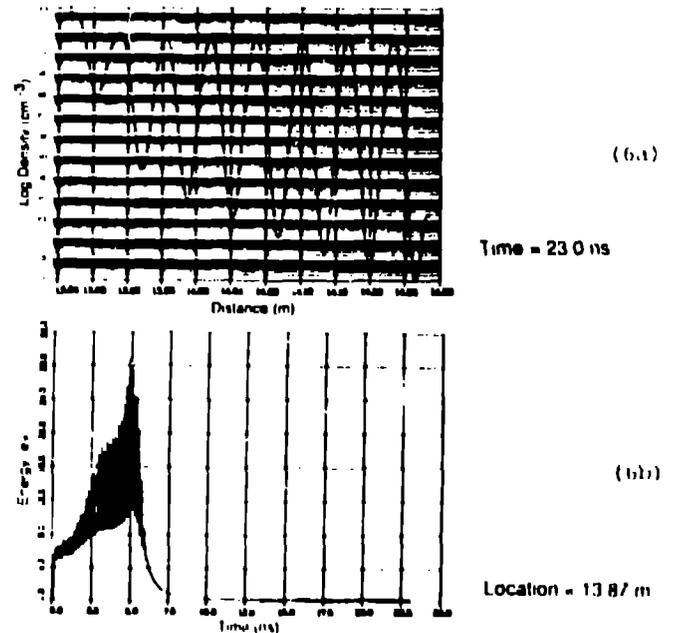


Fig. 6. Shot 64, 20 Torr. Model predictions.

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The assistance of J. Hoffman, W. Beverie, P. Toth (SRLA) and M. Kelly (LANL) is gratefully acknowledged.